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although the constants in this equation were not accurately known, and thus to test the quantum relationship (2). The results of Hull[5] indicate clearly that the quantum relationship (2) holds for the maximum or limiting frequency of the X rays produced at high potentials, but although the range of potentials used by Rutherford (13,200 to 175,000 volts) was sufficient for the accurate determination of the constants of (1) or (3), they cannot be determined from his results, either because such relationships do not hold for very high potentials, or because the X rays had not passed through a sufficient thickness of absorbing material to give the limiting values of the absorption coefficients. The X rays produced at the potentials used by Rutherford and by Duane are of such penetrating power that no special window such as W, figure 1, was necessary. X rays produced at the potentials used in this investigation (2,500 to 10,000 volts) are of such low penetrating power that it was necessary to make the window W as thin as could be made to withstand atmospheric pressure, and to use the thinnest sheets of absorbing material that could be obtained, and still have them of uniform thickness.

Summary.—A relationship such as (3) has been known for some time to hold approximately for X rays of the ordinary range of penetrating power, but the constants have not previously been accurately determined. These results indicate that such a relationship holds for very much softer X rays, and values of the constants have been determined with considerable accuracy. These values are in agreement with those which hold for the higher potentials, as nearly as the latter have been determined.

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[1] W. H. Bragg and W. L. Bragg, *X Rays and Crystal Structure*, p. 180. W. H. Bragg *Phil. Mag.*, March, 1915.

[2] Wm. R. Ham, *Physic. Rev.*, January, 1910.

[3] Duane and Hunt, Proc. Amer. Phys. Soc., *Physic. Rev.*, August, 1915.

[4] Rutherford, Barnes and Richardson, *Phil. Mag.*, September, 1915.

[5] Albert W. Hull, Proc. Amer. Phys. Soc., *Physic. Rev.*, January, 1916.

FURTHER EVIDENCE AS TO THE RELATION BETWEEN CROWN GALL AND CANCER

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1. *Fundamental concepts.*—It is my belief that a diligent study of tumors in plants will help to solve the cancer problem. Expressed in other words, my text is this: Cancer occurs in many kinds of plants in which it passes through an essentially parallel course of development

to that of cancer in man and animals, some allowance, of course, being made for differences in the structure and development of plants. My concept is this, that fundamentally plants and animals are alike, that physical and chemical laws apply equally, that is uniformly, to all living things, and hence that discoveries relative to the fundamental cell-mechanics of animals apply equally to plants, and vice versa.[1] If cancer occurs in plants and is due to a parasite, as I maintain, then cancer in man must also be due to a parasite, and since I show that several kinds of plant cancers are due to the same organism, the differences being due solely to unlike tissue reactions, we may anticipate the same thing to be true in man, and search for one parasite rather than many.

2. *Human and animal tumors for which no cause has been discovered.*—These tumors fall readily into two groups which intergrade more or less. These are (*a*) encapsuled benign tumors, and (*b*) free-growing malignant tumors or cancers. I will here consider only the malignant tumors. There are several types of these; the simplest and the commonest being proliferations (1) of the connective tissues, resulting in fleshy tumors known as *sarcomas*, and (2) of the various kinds of epithelium, resulting in eroding tumors known as *carcinomas*. In addition to tumors of the brain and nervous system, which are sometimes malignant but which may here be left out of account, there are (3) very curious tumors containing mixed tissue elements of two germ layers (connective tissues, cartilage, striped and plain muscle-fibres, glandular tissue, etc.) some of which are benign while others are extremely malignant, and finally, (4) embryonal teratomas which, in addition to the cancerous element, contain numerous foetal fragments, derived from all three of the primitive germ layers, often a great variety of tissue-fragments, variously fused and jumbled, but all embryonic and never coming to maturity.

The leading characteristics of these cancerous tumors are (1) Unlimited cell proliferation emancipated from bodily control; (2) Appearance of destructive secondary tumors, often in vital organs, which tumors are derived from the primary tumor either by development from dislodged creeping and floating tumor cells, or by uninterrupted growth from a chain of tumor cells originating in the primary tumor. These secondary tumors wherever they are developed repeat more or less closely the structure of the parent tumor. Add, to these manifestations, (3) a destructive action on surrounding tissues, which are crushed, absorbed or poisoned, and we have in brief the main phenomena of cancerous growth. The other phenomena are subsidiary and may be left out of account in this brief abstract.

3. *Earlier discoveries in plants.*—In 1907 the author and his colleagues (Townsend and Brown) proved that a common hyperplasia of various cultivated plants which had been for many years under observation in this country and in Europe and for which various causes had been inconclusively assigned (frosts, physiological disturbances, mites, myxomycetes, etc.) was really due to a polar flagellate schizomycete, named by us *Bacterium tumefaciens*. This was first cultivated from tumors on the Paris daisy in 1906, but afterwards it was obtained from various other plants, in several distinct strains (daisy strain, hop strain, etc.) and shown to be cross-inoculable on a variety of plants with resultant tumors in which no bacterial cavities or bacterial occupation of cells, vessels, or intercellular spaces could be seen in fresh material or demonstrated in serial sections by stains, and yet from which the causal organism was readily cultivable in small numbers by the common methods of the bacteriologist.

4. *Further discoveries.*—In 1911 I discovered in inoculated Paris daisies a parenchymatous tumor-strand connecting the primary stem tumors with deep-seated secondary tumors which had developed in the leaves some weeks after the stem inoculations. I also showed these secondary leaf-tumors to be possessed of stem structure, i.e., to have the structure of the primary tumor, thus following the law of cancer in man and animals. These discoveries were fully illustrated and described at that time in United States Department of Agriculture bulletins[2] and elsewhere. From the origin, structure and general appearance of these tumors I likened them to sarcomata.

5. *Other resemblances of crown gall to cancer in man and animals.*—Without entering into details which may be found elsewhere a few other resemblances are here summarized: (1) No parasite visible; (2) Embryonic character and rapid multiplication of the proliferating cells; (3) Loss of polarity in the proliferating tissues; (4) Invasive surface growth of the tumor and absence of a capsule; (5) Non-granulomatous development of secondary tumors; (6) Growth in autonomous species from grafts; (7) Presence of degenerative changes in the proliferating cells as shown by behavior toward stains, by lobed and cleft nuclei, polynuclear cells, etc.; (8) Destruction of surrounding tissues; (9) Defective vascularization and early central necrosis with invasion of the open wounds by secondary parasites and by saprophytes; (10) Frequent return after excision; (11) Presence of atrophy and cachexia.

6. *Possibility of the existence of carcinomas and of mixed tumors in plants.*—Slides were shown suggesting that it is experimentally possible to induce the proliferation of glandular tissue and the epidermis (skin) of plants by bacterial inoculations, but so far no metastases have been obtained. This whole subject, however, is yet in its infancy and further reports will be made from time to time as results are obtained.

7. *Production of embryonal teratomata.*—Last winter I discovered that when growing plants are inoculated in the vicinity of dormant buds a new type of tumor is produced. This tumor bears on its surface diminutive abortive shoots (vegetative or floral), and in its interior, along with the cancer cells, numerous fragments of embryonic tissues, variously fused and oriented, often upside down and curiously jumbled. These tumors have never been seen by the writer in nature or at least if seen not recognized as crown gall tumors, but undoubtedly we shall now find them.[3] These tumors have all been produced with *Bacterium tumefaciens* plated from an ordinary sarcoma-like tumor of the hop received from the Pacific Coast 8 years ago. The plants chiefly experimented on have been Pelargonium, Nicotiana, Lycopersicum, Citrus, and Ricinus. All of these and some others (Mangifera, Allamanda, etc.) have yielded teratoid tumors from inoculations in leaf axils.

The inoculated tobacco also developed secondary teratoid tumors at a distance from the primary tumor in both stems and leaves, i.e., tumors bearing numerous diminutive and abortive shoots, which at longest have lived but a few months. In other words, like the secondary tumors on the Paris daisy they have repeated the structure of the parent tumor but this time that which is repeated is not a simple sarcoma developed out of fundamental tissues but a complex tumor comparable to the embryonal teratomata or atypical teratoids occurring in man. Many attempts have been made in recent years to produce such tumors in animals but hitherto all experimenters have failed. Monsters, it is true, have been produced repeatedly by fragmenting eggs, and in other ways, but always they have been *typical teratoids*, never cancers.

However, the most striking result I have obtained is yet to be told. All the embryomas previously mentioned were obtained by making my bacterial inoculations in the vicinity of dormant buds (totipotent anlage) which were then apparently torn by the rapid growth of the tumor, the fragments being variously distributed in the tumor and there stimulated to develop, the result being embryonic growths of extremely variable size but all referable to the original disturbed shoot-anlage. If, however, inoculations are made in regions not known hitherto to contain totipotent cells, the same results can be obtained, e.g., I have obtained on the tobacco a shoot-bearing tumor from the middle of an internode, and numerous such tumors from various parts of leaves, twenty-seven on a single plant, seven on a single leaf, and too many it would seem to be explained on Cohnheim's theory,[4] i.e., as growths due to the development of embryonic 'cell rests,' which are conceived to be fragments displaced from the embryo in early stages of its growth and enclosed in other tissues where they remain dormant until a cancer stimulus sets them growing.

8. *Bearing of these discoveries on the cancer problem.*—It has been pointed out repeatedly that embryomas are the crux of the whole cancer problem. Hitherto they have remained unexplained. Now I have succeeded in bringing them into correlation with the simpler forms of cancer by showing that they also are specific tissue responses to the stimulus of a specific schizomycete. If one set of plant tissues is inoculated sarcoma develops; if another set, carcinoma (?); if a third set (and this time it must be a complex anlage containing totipotent or nearly totipotent cells), an embryoma develops. To a biologist, therefore, the conclusion is almost irresistible that human cancer must be due to a parasite, and that one parasite may well be the cause of the most diverse forms, as we have seen to be the case in plants. Those who consider plants and animals so different that no conclusion can be drawn from the one to the other will see no interrelation, but I am hoping the recorded facts will make a strong appeal to those who know something about cell metabolism and the similar response of living plants and animals to a great variety of stimuli.

[1] See *J. Cancer Res.*, **1**, No. 2, April, 1916, and *Science*, N. S., **43**, 871, where I have elaborated this idea and also other ideas only touched upon here.

[2] *Bureau of Plant Industry, Bulletins* No. 213 and No. 255.

[3] As this goes to press I have had confirmation of this belief, having received from a florist in Massachusetts a crown gall of the rose showing abortive shoots growing out of stem tumor.

[4] For illustrations of teratomas produced in tobacco leaves by direct bacterial inoculation consult *J. Agric. Res.*, April 24. 1916, Plate 23.